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**APPLICATION  
FOR  
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LETTERS PATENT**

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**FOR:**                   **ANTENNA DEVICE AND TRANSMITTER-  
RECEIVER USING THE ANTENNA DEVICE**

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# ANTENNA DEVICE AND TRANSMITTER-RECEIVER USING THE ANTENNA DEVICE

## BACKGROUND OF THE INVENTION

### Field of the Invention

The present invention relates to a transmitter-receiver having an antenna device and, particularly, to the antenna device of a transmission line type constituted by two lines  
5 opposed to each other.

### Description of the Related Art

In general, an antenna device of transmission line type has a line placed above a planar conductor with a spacing  
10 provided between the line and the planar conductor, and a signal is fed between the line and the planar conductor. Ordinarily, characteristic analysis on such an antenna device is performed by using a mirror-image line emerged in such a position that the mirror-image line and the actual line are symmetrical about  
15 the planar conductor, and the two lines formed by the actual line and the mirror-image line can be regarded as transmission lines. For this reason, this antenna device is called a transmission line type. This antenna device of transmission line type is known as a transmission line T type, a transmission  
20 line M type, a transmission line F type (inverse F type) or the like.

An antenna device used in the field of amateur radio or the like and called "hantena" (see, for example, Japanese Patent Laid-Open No. H9-284028) can be regarded as an antenna having an actual line formed as the mirror-image line in the transmission line M type of device.

The above-described conventional antenna device of transmission line type is formed of transmission lines having a low radiation resistance. In the conventional antenna device of transmission line type, therefore, a feed current several to several ten times larger than that in an ordinary antenna device is required for the antenna elements to obtain the same radiation power as that of the ordinary antenna device. Consequently the antenna directivity sharpens and the frequency band for impedance matching is narrowed.

#### 15 SUMMARY OF THE INVENTION

A first object of the present invention is to realize an antenna device of transmission line type having a broad matching frequency band and capable of being easily adjusted for matching.

20 A second object of the present invention is to provide a transmitter-receiver using mounting along peripheral side portions of a frame to enable flexible designing under restrictions due to the frame structure.

The present invention provides an antenna device of transmission line type having two antenna elements opposed to each other, and a signal is fed between the two antenna

elements, and a variable-capacitance unit capable of changing the electrostatic capacity, and also the variable-capacitance unit being provided at one or both of connection points at which opposite ends of the antenna elements are connected to each other.

The length of each portion of the two antenna elements on the opposite sides of a feed point is equal to or smaller than  $1/4$  of the wavelength of the fed signal.

The two antenna elements are spaced apart from each other by a distance smaller than the wavelength of the fed signal.

The variable-capacitance unit has a variable-capacitance diode, the electrostatic capacity of which changes according to a direct-current voltage applied between the anode and the cathode.

A predetermined direct-current voltage is applied to the variable-capacitance diode from a voltage control unit through an inductance element.

The present invention also provides a transmitter-receiver in which the above-described antenna device is mounted along peripheral side portions of a frame.

In the antenna device and the transmitter-receiver arranged as described above, the electrostatic capacity of the variable-capacitance unit inserted at one or both of the connection points at which the opposite ends of the two antenna elements are connected to each other is adjusted to achieve matching to the desired impedance at the feed point and, hence, matching to a signal of the desired frequency.

Also, the antenna device of the present invention is mounted along peripheral side portions of a frame to ensure that the antenna elements have a sufficiently effective length without a restriction due to the frame size.

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#### BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings wherein:

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Fig. 1 is a block diagram showing the construction of an antenna device which represents a first embodiment of the present invention;

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Figs. 2(a) and 2(b) explain the principle of the operation of the antenna device shown in Fig. 1, and Fig. 2(a) is a plan view showing the construction of an essential portion, and Fig. 2(b) is an equivalent circuit diagram of the antenna device;

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Fig. 3 is a diagram showing a standing wave distribution and the flow of current in the antenna device shown in Fig. 1;

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Fig. 4(a) to 4(d) show the directivity of the antenna device shown in Fig. 1, and Fig. 4(a) is a plan view showing the directivity of the horizontal portions of the antenna elements, and Fig. 4(b) is a cross-sectional view showing the directivity as seen in a direction parallel to the lengthwise direction of the antenna device, and Fig. 4(c) is a plan view

showing the directivity of the vertical portions of the antenna elements, and Fig. 4(d) is a cross-sectional view showing the directivity as seen in a direction from above the antenna device; and

5        Fig. 5(a) and 5(b) showing the construction of antenna device which represent a second embodiment of the present invention, and Figs. 5(a) is a plan view, and Fig. 5(b) is a diagram showing a mounted state.

10        DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described with reference to the accompanying drawings. Fig. 1 is a block diagram showing the construction of an antenna device which represents a first embodiment of the present invention.

15        The antenna device of the present invention is an antenna device of transmission line type in which a signal is fed to two antenna elements opposed to each other. A variable-capacitance unit is inserted at one or both of two connection points at the opposite ends of two antenna elements  
20        are connected to each other. Impedance matching frequency of this antenna device can be changed by adjusting the electrostatic capacity of this variable-capacitance unit.

As shown in Fig. 1, the antenna device of this embodiment has the first antenna element 10 and the second antenna element  
25        11 opposed to each other. A signal is fed from a signal source 14 connected between the first antenna element 10 and the second antenna element 11.

The first variable-capacitance unit 12 and the second variable-capacitance unit 13 are respectively inserted at the connection points at which the opposite ends of the first antenna element 10 and the second antenna element 11 are connected to each other.

The first antenna element 10 and the second antenna element 11 extend to opposite directions from the feed point and have a length equal to or smaller than  $1/4$  of the wavelength of the fed signal. The first antenna element 10 and the second antenna element 11 are spaced apart from each other by a distance sufficiently small relative to the wavelength of the fed signal. Therefore, the first antenna element 10 and the second antenna element 11 function as an antenna device of transmission line type.

Each of the first variable-capacitance unit 12 and the second variable-capacitance unit 13 has a variable-capacitance diode 16. The electrostatic capacity between the terminals of the variable-capacitance diode 16 changes by a control voltage (direct-current voltage) supplied from a voltage control unit 15. As shown in Fig. 1, the cathode of the variable-capacitance diode 16 is ac-connected to the first antenna element 10 via a capacitor 17a, and the anode is ac-connected to the second antenna element 11 via a capacitor 17b. The variable-capacitance diode 16 is also connected to the voltage control unit 15 via coils 18a and 18b which block leakage of the high-frequency signal. A positive direct-current voltage is applied to the cathode of the

variable-capacitance diode 16. The first  
variable-capacitance unit 12 and the second  
variable-capacitance unit 13 are not limited to the arrangement  
using the variable-capacitance diode 16, if the electrostatic  
5 capacity can be changed. For example, a trimmer capacitor  
or the like may be used for the first variable-capacitance  
unit 12 and the second variable-capacitance unit 13.

The principle of the operation of the antenna device of  
this embodiment shown in Fig. 1 will now be described with  
10 reference to Figs. 2(a) and 2(b).

Figs. 2(a) and 2(b) are diagrams for explaining the  
principle of the operation of the antenna device shown in Fig.  
1. Fig. 2(a) is a schematic plan view showing the construction  
of an essential portion, and Fig. 2(b) is an equivalent circuit  
15 diagram of the antenna device.

For ease of description, it is assumed that the first  
antenna element 10 and the second antenna element 11 are two  
lines maintained in parallel with each other. It is also  
assumed that the distance  $D$  between the first antenna element  
20 10 and the second antenna element 11 is sufficiently small  
relative to the wavelength of the signal fed from the signal  
source 14, and that the distances  $l_1$  and  $l_2$  from the feed point  
to the first variable-capacitance unit 12 and the second  
variable-capacitance unit 13 are equal to or smaller than about  
25  $1/4$  of the wavelength. Accordingly, the antenna device shown  
in Fig. 1 can be assumed to be a device of such a construction  
that two parallel lines (parallel dual lines) are connected



on the right and left sides of the feed point. Radio wave radiation from the parallel dual lines is limited and the radiation resistance of the parallel dual lines is lower than that of a dipole antenna or the like.

5        The impedance  $Z_1$  on the left-hand side as seen from the feed point on the parallel dual lines shown in Fig. 2 and the impedance  $Z_2$  on the right-hand side are expressed as shown below. If the radiation resistance on the left-hand side is  $R_1$ ; the radiation resistance on the right-hand side is  $R_2$ ;  
10    the reactance component on the left-hand side is  $X_1$ ; and the reactance component on the left-hand side is  $X_2$ , the impedance  $Z_1$  and the impedance  $Z_2$  are shown by the following equations:

$$Z_1 = R_1 + jX_1 \dots\dots (1)$$

$$Z_2 = R_2 + jX_2 \dots\dots (2)$$

15    Thus, the equivalent circuit shown in Fig. 2(b) can be substituted for the circuit shown in Fig. 2(a).

The capacitive reactances  $x_1$  and  $x_2$  of the first variable-capacitance unit 12 and the second variable-capacitance unit 13 are expressed from the  
20    electrostatic capacities  $C_1$  and  $C_2$  of the first variable-capacitance unit 12 and the second variable-capacitance unit 13 and the angular frequency  $\omega$  of the signal supplied from the signal source 14 by the following equations:

25         $x_1 = -j/\omega C_1 \dots\dots (3)$

$$x_2 = -j/\omega C_2 \dots\dots (4)$$

These electrostatic capacities  $C_1$  and  $C_2$  are converted into the reactance components  $X_1$  and  $X_2$  appearing at the feed point. That is, there are relationships expressed by the following equations (5) and (6):

$$5 \quad X_1 = -jZ_0 \{x_1 - Z_0 \tan(\beta L_1)\} / \{Z_0 + x_1 \tan(\beta L_1)\} \dots\dots (5)$$

$$X_2 = -jZ_0 \{x_2 - Z_0 \tan(\beta L_2)\} / \{Z_0 + x_2 \tan(\beta L_2)\} \dots\dots (6)$$

where  $Z_0$  is the characteristic impedance of the parallel dual lines and  $\beta$  is a phase constant of the parallel dual lines.

The impedance  $Z$  at the feed point is equal to the impedance of the parallel connection of the right and left impedances  $Z_1$  and  $Z_2$  and is expressed from the above-described equations (1) and (2) by the following equation:

$$15 \quad Z = Z_1 Z_2 / (Z_1 + Z_2) \\ = \{ (R_1 R_2 - X_1 X_2) (R_1 + R_2) + (X_1 R_2 + X_2 R_1) (X_1 + X_2) \} \\ / \{ (R_1 + R_2)^2 + (X_1 + X_2)^2 \} + j \{ (R_1 R_2 - X_1 X_2) (X_1 + X_2) \\ - (X_1 R_2 + X_2 R_1) (R_1 + R_2) \} / \{ (R_1 + R_2)^2 + (X_1 + X_2)^2 \} \dots\dots (7)$$

20 Since the radiation resistance is generally proportional to the length, an approximation:

$$R_1 \doteq R_2 = R \dots\dots (8)$$

can be made if the lengths of the left and right antenna elements are in a relationship  $l_1 \doteq l_2$ . Equation (8) is substituted

25 in equation (7) to obtain:

$$Z \doteq R (X_1^2 + X_2^2 + 2R^2) / \{ 4R^2 + (X_1 + X_2)^2 \} \\ - j (X_1 + X_2) (X_1 X_2 + R^2) / \{ 4R^2 + (X_1 + X_2)^2 \} \dots\dots (9)$$

As can be understood from equation (9), the reactance component of the impedance  $Z$  at the feed point is zero and the impedance  $Z$  is a pure resistance if the condition  $X_1 + X_2 = 0$  is satisfied. That is,  $X_1$  and  $X_2$  are set to such reactances that their polarities are opposite to each other, that is, either  $X_1$  or  $X_2$  is an inductive reactance and the other is a capacitive reactance, and that reactances are equal in magnitude to each other. This can be realized by adjusting the electrostatic capacities  $C_1$  and  $C_2$ , as can be understood from equations (3) to (6). If a definition:

$$X_1 = -X_2 = X \dots\dots (10)$$

is made, equation (9) can be simplified into:

$$Z = (X^2 + R^2)/2R \dots\dots (11)$$

From the above explanation it can be understood that the antenna device of this embodiment can be matched to the signal having the desired frequency if the electrostatic capacity  $C_1$  of the first variable-capacitance unit 12 and the electrostatic capacity  $C_2$  of the second variable-capacitance unit 13 are adjusted so that the right side of equation (11) is equal to the desired impedance at the feed point while satisfying the relationship shown in equation (10).

Adjustment of the electrostatic capacity  $C_1$  and the electrostatic capacity  $C_2$  can be performed by changing the control voltages supplied from the voltage control unit 15 to the first variable-capacitance unit 12 and the second variable-capacitance unit 13. Even when the angular frequency  $\omega$  of the signal source 14 is changed, the matching

conditions can be satisfied by readjusting the control voltages.

The explanation has been provided by assuming that the radiation resistances are approximately equal, i.e., by using the condition shown in equation (8). However, even in a case where  $R_1$  and  $R_2$  differ from each other, a solution can be obtained from equation (7) such that the reactance component is zero and the impedance at the feed point is equal to the desired value.

The directivity of the antenna device of this embodiment in a case where each length of the first and second antenna elements is equal to or smaller than about  $\lambda/2$  will be described by way of example.

Fig. 3 is a diagram schematically showing a standing wave distribution and the flow of current in the antenna device shown in Fig. 1.

The first antenna element 11 and the second antenna element 12 exhibit a standing wave distribution such as shown in Fig. 3 when their length is  $\lambda/2$ . However, when the length is shorter than  $\lambda/2$ , a current having an amplitude lower than the maximum amplitude of a standing wave but not zero flows through the vertical portions of the antenna elements shown in Fig. 3. The vertical portions are shorter than the horizontal portions of the antenna elements but have substantially the same radiation resistance as that of the horizontal portions since they are not parallel dual lines. Therefore, when  $l_1 + l_2$  is substantially shorter than  $\lambda/2$ , that is, a current not

negligible in comparison with that in the horizontal portions  
flows in the vertical portions of the antenna elements,  
electric power radiated from the antenna device is the  
resultant power from both the horizontal portions of the  
5 antenna elements and the vertical portions of the antenna  
elements.

Figs. 4(a) to 4(d) are diagrams showing the directivity  
of the antenna device shown in Fig. 1. Fig. 4(a) is a plan  
view showing the directivity of the horizontal portions of  
10 the antenna elements. Fig. 4(b) is a cross-sectional view  
showing the directivity as seen in a direction parallel to  
the lengthwise direction of the antenna device. Fig. 4(c)  
is a plan view showing the directivity of the vertical portions  
of the antenna elements. Fig. 4(d) is a cross-sectional view  
15 showing the directivity as seen in a direction from above the  
antenna device.

As shown in Figs. 4(a) to 4(d), this antenna device  
exhibits a figure-8 directional pattern in all the directions,  
although the directivity varies in beam width and polarization  
20 direction depending on the plane in which the directivity is  
seen. The beam width and the gain distribution to the planes  
of polarization can be changed by changing  $l_1$ ,  $l_2$  and the distance  
D. Thus, the antenna device of this embodiment has wide  
directivities in various directions.

25 As described above, the antenna device of this embodiment  
is capable of broadening the matching frequency bandwidth by  
adjusting the electrostatic capacities of the

variable-capacitance units. For example, if, in a wireless communication system using a plurality of frequency channels, control voltages optimized in relation to the frequencies are applied to the variable-capacitance diodes, even matching to  
5 one of the frequency channels deviating from the original band can be achieved.

In the antenna device of this embodiment, since a loading effect is produced by addition of the variable-capacitance units, matching can be performed even when the antenna element  
10 length is reduced from  $\lambda/2$ . Therefore the antenna device can be reduced in size.

Since the antenna device of this embodiment has broad directivity, it can be suitably used in a mobile wireless communication terminal in which the direction of receiving  
15 of electric waves cannot be determined in advance.

While the construction in which variable-capacitance units are provided at the both ends of the first antenna element  
10 and the second antenna element 13 has been described, the same effect can also be obtained by providing a  
20 variable-capacitance unit at only one end.

An antenna device which represents a second embodiment of the present invention will be described with reference to Figs. 5(a) and 5(b).

Figs. 5(a) and 5(b) are diagrams showing the construction  
25 of antenna device which represents a second embodiment of the present invention. Fig. 5(a) is a plan view and Fig. 5(b) is a diagram showing a mounted state.

As shown in Fig. 5(a), in the antenna device of the second embodiment the lengths of a first antenna element 20 and a second antenna element 21 in the left and right direction is extended and a first variable-capacitance unit 22 and a second variable-capacitance unit 23 are placed about positions defined by an integer multiple of  $\lambda/2$ . A signal is fed to the first antenna element 20 and the second antenna element 21 from a signal source 24 provided between these antenna elements. Also with respect to this construction, the reactances of the first variable-capacitance unit 22 and the second variable-capacitance unit 23 can be calculated by using equations (5) and (6) shown above.

In the antenna device of this embodiment, since the reactance as seen from the feed point is the same as that in the first embodiment, matching can be performed under conditions similar to those in the first embodiment, although there is a radiation resistance difference.

It is not necessary required that the dual lines of the antenna elements is parallel straight lines. Matching can be performed even in an arrangement in which the dual lines are bent. If the antenna elements are mounted along peripheral side portions of a frame as shown in Fig. 5(b) for example, the antenna elements can have a sufficiently long effective length without a restriction due to the frame size. Further, the dead angle of the directivity can be reduced by bending the antenna elements.

In the construction of this embodiment, the device can be flexibly designed under conditions due to the frame structure to be obtained as an antenna device of transmission line type having a broad directivity. Needless to say, the mounting method shown in Fig. 5(b) can be applied to the antenna device of the first embodiment shown in Fig. 1.

While this invention has been described in connection with certain preferred embodiments, it is to be understood that the subject matter encompassed by way of this invention is not to be limited to those specific embodiments. On the contrary, it is intended for the subject matter of the invention to include all alternative, modification and equivalents as can be included within the spirit and scope of the following claims.